

# A Reconnaissance Gravity Survey of the Island of Kauai, Hawaii<sup>1</sup>

HAROLD L. KRIVOY,<sup>2</sup> MELVILLE BAKER, JR., and EUGENE E. MOE<sup>3</sup>

**ABSTRACT:** A large Bouguer anomaly on Kauai, similar to anomalies found at most of the other major volcanoes of the Hawaiian Islands, lies about 10 miles east of the caldera indicated by geologic mapping. Another gravity high suggests a second center of volcanism just west of the island.

Average Bouguer values on Kauai are higher than on other Hawaiian islands, indicating either that the crust beneath Kauai is 1–2 km thinner than it is beneath the eastern part of the Hawaiian Chain, or that the zone of increased density in the dike complex lies closer to the surface at Kauai than do similar cores within other islands of the chain.

BETWEEN THE 26TH AND 30TH of May, 1963 the authors carried out a reconnaissance gravity survey of the island of Kauai in Hawaii. Stations occupied are shown in Figure 1, a generalized topographic map of Kauai. A large part of Kauai is rugged and inaccessible, and in the course of this preliminary survey most available roads were traversed. A more complete picture of the gravity field of Kauai must await further penetration of the island with meters carried by helicopters, boats, and ground parties.

The present gravity survey was planned to take advantage of the availability of a LaCoste and Romberg geodetic gravity meter and of recently completed topographic mapping on Kauai. The results are intended to supply a general idea of the local gravity configuration on Kauai, to permit comparison of the gravity field on Kauai with that on other islands of the state of Hawaii, and to serve as a guide for further investigations.

## OPERATIONAL DETAILS

The Kauai gravity net was carried from bases on Hawaii, Maui, and Oahu. A new primary base was established at Lihue Airport; the instrument was read directly in the center of a rectangular cement pad used by the U. S. Weather Bureau as a theodolite base. This pad is between the airport terminal building and

the weather dome. A secondary base was established on the ground near the front steps of the Lani Motel in Lihue. Tentative base values, tied to G. P. Woollard's base (personal communication) at the old International Air Terminal, Oahu, are as follows:

STATION	GBV
Lani Motel	979,044.3
Lihue Airport	979,037.2

Table 1 lists repeat readings made at Lani Motel during this survey. The negligible diurnal drift, as well as the small total drift in the 5-day period, provide confidence for the zero-drift treatment accorded data collected in any single day. The repeat readings in Table 1 have been corrected for tidal attraction according to Goguel (1962).

The table of principal facts is reported elsewhere (Hawaii Inst. Geoph., 1965, Table 7).

TABLE 1  
REPEAT READINGS MADE AT LANI MOTEL,  
LIHUE, KAUAI

DATE	TIME (HST)	READINGS (mgal)
5/26/63	18:28	2690.66
5/27/63	07:16	2690.64
5/27/63	20:27	2690.69
5/28/63	07:09	2690.77
5/28/63	20:00	2690.60
5/29/63	07:35	2690.75
5/29/63	19:37	2690.74
5/30/63	08:10	2690.75

<sup>1</sup> Publication authorized by the Director, U. S. Geological Survey.

<sup>2</sup> U. S. Geological Survey, Denver, Colorado.

<sup>3</sup> U. S. Geological Survey, Kauai, Hawaii.

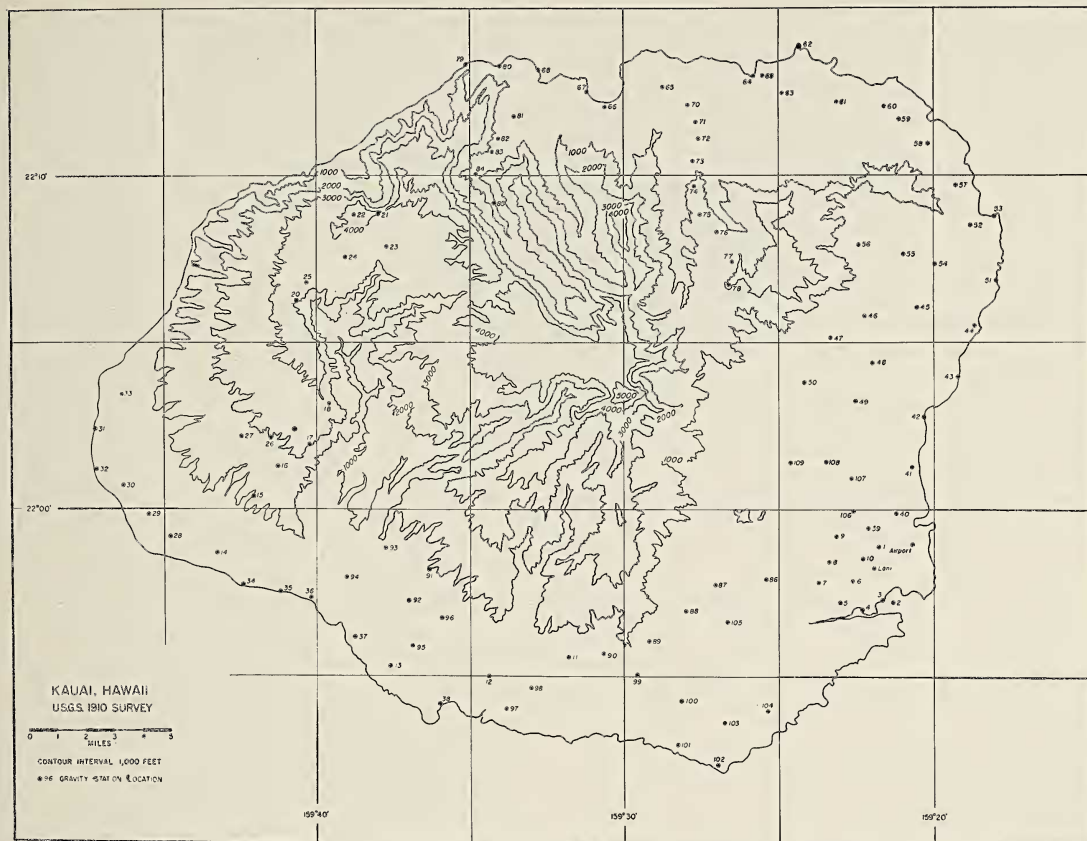


FIG. 1. Topography of Kauai, Hawaii, showing gravity meter stations.

Stations were selected and located on U. S. Geological Survey 7½-minute compilation prints with a scale of 1:24,000. Figures 1 and 2 are based on existing U. S. Geological Survey 1:62,500 maps of Kauai, to which station locations were transferred for greater convenience.

#### DETAILS OF INTERPRETATION

For ease in comparing results of this survey with those of previous Hawaiian surveys, the Bouguer anomalies are based on a combined elevation correction using 2.3 as bulk density down to sea-level. The use of density 2.3 has been discussed by Woollard (1951) for Oahu gravity and by Krivoy and Eaton (1961) for the gravity of Kilauea volcano on Hawaii island. As the gravity survey extends westward from the fresh, vesicular, and relatively uniform flows of Hawaii toward the more deeply weathered older islands of the state, the choice of 2.3 dens-

ity remains convenient albeit less defensible. Not much is known about the extent to which the more deeply weathered islands are mantled by soil and saprolite with density as low as 1.0. Soil conservation studies, where they have been made, habitually are concerned with only the first few feet of soil-cover—the zone of interest in agriculture and in erosion studies. Kauai, therefore, may be largely overlain by varied erosional products with densities much less than 2.3. Macdonald et al. (1960) describe the deep weathering and the vegetative cover on Kauai which make determination of strike and dip impossible in most places.

It should be noted that assuming too high a density for the lavas of Kauai would result in a Bouguer configuration which undervalued high elevation stations. Thus, the unusually high Bouguer anomalies mapped in Kauai would be even larger if a more realistic (smaller) density value were known and were applied.

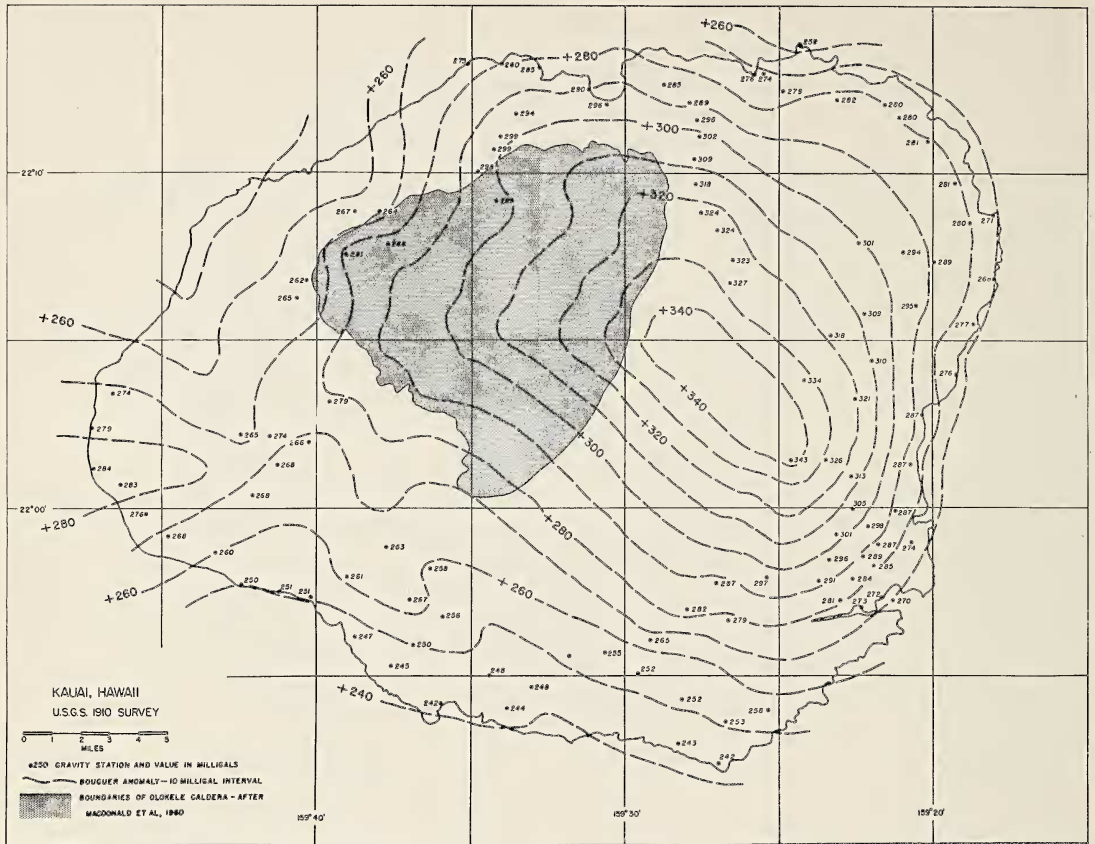


FIG. 2. Bouguer anomaly map of Kauai, Hawaii, showing station values based on 2.3 density. No topographic corrections have been included.

IMPLICATIONS OF THE BOUGUER ANOMALY MAP (FIG. 2)

Gravity work by Woollard (1951) on Oahu and by Krivoy and Eaton (1961) at Kilauea clearly indicates that Hawaiian volcanoes display distinctive Bouguer gravity highs which appear to be associated with their centers of volcanism. Work by Kinoshita et al. (1963) upon Kohala, Mauna Kea, and Mauna Loa on the island of Hawaii bears out the earlier indications; and unpublished studies by Krivoy and Kinoshita show diagnostic highs for Mauna Loa on Molokai, for Palawai Basin on Lanai, and for Haleakala on Maui.

Local Bouguer anomaly highs of approximately 70 mgal are centered on currently active Hawaiian volcanoes. In the cases listed above for Oahu, Hawaii, Maui, Lanai, and Molokai, the Bouguer highs coincide with major centers

of volcanism, as revealed by topographic and geologic evidence. In two interesting examples, Koolau on Oahu and Kohala on Hawaii, the Bouguer high is displaced from the topographic high. At Koolau erosion and/or faulting have removed the original topographic high over the central volcanic complex, the highest remaining portion of the shield being its southwestern flank. The Bouguer high is centered on the eroded, low-lying dike complex. At Kohala the Bouguer high is displaced southeastward from the present summit. Possibly it reveals the dense central part of an ancestral Kohala shield that was buried by flows from the younger Mauna Kea volcano.

On the island of Hawaii (Kinoshita et al., 1963), terrain corrections were computed out to zone N (Hayford-Bowie). They provided large corrections—as much as 50 mgal—for

stations on the rather steep Mauna Kea. The gravity configuration over the low shield volcano Kilauea, however, was only slightly modified by consideration of terrain both on land and off-shore. The more subtle gravity anomalies, such as those on Mauna Kea and Mauna Loa, were "improved" by the addition of terrain correction, albeit this was in a direction which emphasized correlation between gravity and topography. Strong gravity features, such as the Kohala and Kilauea anomalies, were increased in size and gradient but were not seriously displaced in the final terrain-corrected product. On Hawaii, for example, stations at the Bouguer high on Kohala volcano received less than 6 mgal of terrain correction. Stations on Kilauea received less than 5 mgal. The major Kauai Bouguer anomaly, in this same sense, would be augmented but not seriously shifted.

Figure 2 shows the location of gravity stations and the Bouguer value for each on the island of Kauai. It also shows the location of the Olokele caldera mapped by Stearns (1946) and by Macdonald et al. (1960). Macdonald et al. (1960:32-33) state that "the major caldera of the Kauai shield" is "twice the size of Mokuaweoweo on Mauna Loa . . . but its boundaries are not accurately known." The Bouguer high, as mapped and contoured on Figure 2, does not coincide with the caldera inferred from geologic data. The 340-mgal high is centered about 10 miles east of the center of Olokele caldera. If the relations are similar to those of the other Hawaiian volcanoes studied, the gravity high outlines the most persistent source of lava responsible for building the Kauai shield and probably the caldera site, but the exact relationship between Bouguer high, topographic high, and mapped caldera complex requires further study.

The absence of a gravity nose extending from the gravity high, such as that along the east rift zone of Kilauea, is in agreement with the absence of any marked submarine ridge radiating outward from the island in that direction.

A second anomaly on Kauai is the west-trending high which emerges on the west side of the island. Mapping by Stearns (1946) suggests that a center of volcanism was once active and formed the elongate ridge presently sur-

mounted by Niihau, the island just west of Kauai. Macdonald et al. (1960) show many dikes in west Kauai which could be an extension of a Niihau volcanic center. It should be possible to clarify the situation with additional gravity measurements, mainly on Niihau. However, because of the angle between the two elongate Kauai gravity highs as presently mapped, it does not seem likely that they relate to branches of a single volcanic system. Rather, it would appear that they point to an intergrowth of two distinct volcanoes.

#### LOCAL GRAVITY FIELD

Woollard (1951) offered the first complete interpretation of the gravity field of one of the Hawaiian Islands (Oahu). In this perceptive paper he described the probable source of the Waianae and Koolau gravity highs as the intrusive complexes which mark their volcanic centers. This interpretation has been confirmed by recent studies of the gravity fields of active Hawaiian volcanoes (Kinoshita et al., 1963). An additional mass excess may be provided by deeply ponded dense caldera fill. The juxtaposition of intrusive complexes and caldera fill with density as great as 3, and of clinkery or scoriaeous flow basalts with density of about 2.3, may produce the observed Bouguer anomaly.

#### REGIONAL GRAVITY FIELD

If Figure 2 is compared with the published Bouguer anomaly maps of Kilauea, Kohala, Mauna Loa, Mauna Kea, Koolau, and Waianae, a striking difference is readily apparent. Kauai Bouguer values, both high and low, are 20-25 mgal greater than are corresponding highs and lows on the volcanoes listed.

Woollard and Strange (1962) offered important data which bear on the gravity configuration of the Pacific Basin. With an assumption of 0.4 density contrast between crust and mantle, Kauai's gravity (high as compared with the other volcanoes mentioned) could be explained by up-warping and crustal thinning of 4,000-5,000 ft. If the same density contrast is as great as 0.7, crustal thinning could be less than 3,000 ft.

The Bouguer increase might be due also to a larger and/or more dense dike complex at

the seat of Kauai volcanism than is present beneath the other volcanoes.

Geologic intuition leads to the conclusion that the Hawaiian Chain is growing toward the southeast. Younger islands such as Hawaii and Maui are thought to be undercompensated. Conversely, older islands might be expected to be in better adjustment. Were all other factors equivalent, this would yield lower Bouguer values on Kauai—actually the reverse of our findings.

No one has suggested that some of the older islands might be emerging due to erosional stripping. This would involve the mechanism of crustal thinning and would explain an increased Bouguer field.

As another alternative, it is conceivable that Kauai (as are the other islands) is still undercompensated, but that it erupted and grew on the ocean floor in a region of inherently thinner crust.

#### REFERENCES

- GOGUEL, JEAN. 1962. Tidal gravity corrections for 1963. *Geoph. Prosp.*, Vol. 10, Suppl. 1, Dec. 1962.
- HAWAII INSTITUTE OF GEOPHYSICS. 1965. Data from gravity surveys over the Hawaiian Archipelago and other Pacific islands. Hawaii Inst. Geoph. Rept. 65-4, March 1965. 10 tables.
- KINOSHITA, W. T., H. L. KRIVOVY, D. R. MABEY, and R. R. MACDONALD. 1963. Gravity survey of the island of Hawaii. U. S. Geol. Survey Prof. Paper 475-C:C114-C116.
- KRIVOVY, H. L., and J. P. EATON. 1961. Preliminary gravity survey of Kilauea volcano, Hawaii. U. S. Geol. Survey Prof. Paper 424-D: D205-D208.
- MACDONALD, G. A., D. A. DAVIS, and D. C. COX. 1960. Geology and ground-water resources of the island of Kauai, Hawaii. Hawaii Div. Hydrography Bull. 13, 212 pp.
- STEARNS, H. T. 1946. Geology and ground-water resources of Lanai and Kahoolawe, Hawaii. Hawaii Div. Hydrography Bull. 8, 177 pp.
- WOOLLARD, G. P. 1951. A gravity reconnaissance of the island of Oahu. *Am. Geoph. Union Trans.* 32(3):358-368.
- and W. E. STRANGE. 1962. Gravity anomalies and the crust of the earth in the Pacific Basin. In: *The crust of the Pacific Basin*. Am. Geoph. Union Geoph. Monogr. 6, pp. 60-80.